PLANNING OF MULTIPLE FEEDERS ELECTRICAL DISTRIBUTION SYSTEM

By

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FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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18.05.2011

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TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ahmad Sollehin bin Nordin

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to God for giving me the strength and health to complete this project. Not forgotten to my parents and all my family members for providing everything, such as money and advises, which is most needed in this project.

I would like to thank my supervisor, Dr Nirod Chandra Sahoo for sharing his knowledge and giving me the support and guidance throughout the project.

My appreciation to Universiti Teknologi PETRONAS especially Electrical and Electronics Engineering Department, by providing me the necessary assets and resources, not only to accomplish my task, but to enrich my knowledge further.

Last but not least, I offer my regards to those who support me especially all my friends and technicians in Electrical and Electronics Engineering Department for contributing their assistance and ideas for this project.

ABSTRACT

Electrical Distribution System is a system to distribute electricity to users. Electricity that is being distributed comes from generation station where the electrical power is generated. The electrical power is then being transmitted through Transmission System to substations to be distributed to the users. Electrical Distribution System is very important because it affects the end users directly, thus distribution system planning is very essential. In general, distribution system planning process involves selecting the location of the substation, configuring how the substation connects with all the nodes, and selecting the conductor to be used as feeder for all the branches in the distribution system. In this project, several algorithms are implemented to design an electrical distribution system which are (1) Optimal Feeder Path Algorithm, (2) Modified Load Flow Algorithm, (3) Optimal Branch Conductor Selection Algorithm, and (4) Optimal Location of Substation Algorithm. These four algorithms are combined together to design a distribution system which provides high node voltages, low real and reactive power losses of branches, and low installation and operating costs. Three types of design are considered in this project, (1) single feeder distribution system, (2) two feeders distribution system, (3) three feeders distribution system.

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LIST OF ABBREVIATIONS

IT	number of iteration
j	branch no.
i	node no.
NB	total number of nodes
LN1	total number of branches
PL(i)	real power load of ith node
QL(i)	reactive power load of ith node
|V(i)|	voltage magnitude of ith node
R(j)	resistance of jth branch
X(j)	reactance of jth branch
I(j)	current flowing through branch j
P(m2)	total real power load fed through node m2
Q(m2)	total reactive power load fed through node m2
LP(j)	real power loss of branch j
LQ(j)	reactive power loss of branch j
IS(j)	sending node of branch j
IR(j)	receiving node of branch j
PLOSS(IT)	total real power loss of ITth iteration
QLOSS(IT)	total reactive power loss of ITth iteration
LAC(j)	levelized annual cost of real power loss of branch j
Kp	levelized annual demand cost of losses
KE	energy cost of losses
T	time
Lsf	loss factor
LCI(j)	levelized annual cost of capital investment

cd	conductor code name
C(cd)	cost of the line for cd conductor
A(j)	conductor size of branch j
LEN(j)	length of branch j
a	carrying charge rates

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Power system is composed of three main parts, generation, transmission, and distribution. Electrical distribution system is the final system of delivering electrical power to consumers. In the following sections, there will be discussions on the theory, literature review, and methodology behind electrical distribution system. Electrical distribution system is important as it has direct effects on consumer's electrical power usage.

1.2 Problem Statement

Electrical power is a basic necessity to modern world. The expansion of existing industrial, commercial, and residential areas and the development of new areas required development of new methods in planning electrical distribution system to ensure the consumers can be provided with continuity in electrical power supply. New methods are constantly being created to design a distribution system in which lower the cost for installation, maintenance, and operation of the system.

1.3 Objective and Scope of Study

In order to address the problem stated above a distribution system planning method is designed to provide the solution of the distribution system by minimizing the real power loss, which leads to reduction in installation and operation costs of the system. The system designed also need to be able to maintain the voltage level of all the buses in the system to be higher than the minimum voltage. Four algorithms are simulated to design and analyze the system, to select the most appropriate conductor type for the system with given constraints, and to locate the suitable location of the substation of the system. This project is simulated on 54 bus system and 21 bus system.

CHAPTER 2
LITERATURE REVIEW AND THEORY

This chapter will discuss in depth regarding electrical distribution system and its planning process.

2.1 Electrical Power System

Electrical energy is produced by the process of energy conversion. The electrical power system is a network of interconnected components which electrical energy is generated by conversion of various forms of energy. Common forms of energy that are converted are potential energy, kinetic energy, and chemical energy. The electrical power system consists of three main parts; generation system, transmission system, and distribution system. Figure 1 shows the main idea of electrical power system. Electrical energy is generated at the generation station by conversion of primary source of energy to electrical energy. The voltage output at the generation end is stepped up to higher voltage level (e.g. 765kV or 400kV) for transmission purpose using step up transformer [1].

Transmission system is where the energy transmission process takes place. Electrical power is transmitted at high level voltage from sending end substation. At the receiving end substation, the voltage level is stepped down (e.g. 66kV or 33kV). After the sub transmission system, the voltage is stepped down to 11kV at the Primary Distribution substation. At this substation, some of the electricity is delivered to medium large consumers. Secondary distribution system is another distribution system for delivering power to small consumers at 230 V and 400 V [2].

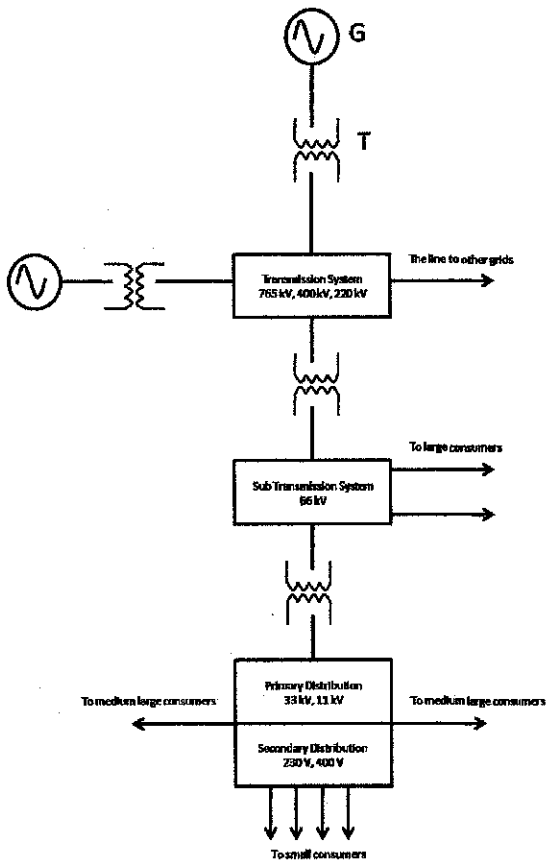

Figure 1 Single line power system network

2.2 Electrical Distribution System

Distribution system is the final system for delivering electricity to consumers. A distribution system delivers electricity from the distribution substation to consumers. Standard distribution system network would include medium-voltage(less than 50kV) power lines, electrical substations, power transformers, and low-voltage(less than 1000V) distribution wiring [3]. Distribution system begins at the main substation. Main substation's components are divided into 3 parts;

1) Feeders: Conductors which connect the main substation to various distribution substations. There is no tapping from the feeders, which means the current loading of a feeder is the same along its entire length.

2) Distributors: Conductors that radiate out from distribution substations to the location of the consumers. Various tapping are taken from the Distributors, therefore the current along the distributor is vary at different points.

3) Service Mains: The links connecting the distributor and the consumer terminals.

2.3 Main Components of Distribution System

A distribution system consists of facilities, equipments, and components that connect a transmission system to the consumers' machines or loads. A typical distribution system consists of:

1) Substation

   A substation is a high voltage electrical system facility. It functions as switch to turn in or out generators, equipment, circuit, and lines from a system. It is also used to change alternating current (AC) to direct current (DC), and vice versa, and to change the voltage level of the electrical power.

2) Distribution feeder circuit

   Distribution feeder circuits are the connectors between the output terminals of a distribution substation and the input of primary circuits. The distribution feeder circuit conductors leave the substation from a circuit breaker. A circuit breaker is an automated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Several distribution feeder circuits can leave a substation to reach to consumers located at different locations.

3) Switches

Switches are installed at strategic locations to control the power distribution for load balancing or sectionalizing. Switches also enable personnel to maintain, repair, and upgrade part of the equipment and the system. Several types of switches are:

- Circuit breaker switches
- Single-pole disconnect switches
- Three pole ground operated switches

4) Protective Equipment

There are many type of protective equipments in a distribution system such as protective relays, cut out switches, disconnect switches, lightning arresters, and fuses. These protective equipments may work individually or in combination to open the circuit in the system in the event of short circuit, lightning strikes, or any disruptive events occur. Whenever circuit breakers open, the circuit is deenergized. To ensure the system can provide electrical power consistently to customers, the distribution system is often designed with two or more feeders to the customers. In the event of one feeder is short circuited, the other feeder can continue to deliver power to the customers.

5) Distribution Transformers

Distribution transformers reduce the voltage of the system to meet the customers' requirement. The voltage varies depends on the customers, either residential customers, commercial customers, or light industry customers.

2.4 Objectives of Distribution System

Below are objectives of an electrical distribution system[3];

1) To provide electrical power to various urban, rural, and industrial consumers in respective area.
2) Optimal security of supply and duration of interruption.
3) Safety of consumers and utility personnel.
4) To provide electrical power that satisfy requirements as stated below:
    - Balanced three phase supply.
    - High power factor.
    - Voltage fluctuates in allowable level.
    - Low voltage drop.
    - Minimal interruption in power supply.

2.5 Requirements of a Practical Distribution System

1) Electrical power supply should be continuous. In the event of breakdown occurs, the system should be able to begin supplying power again in the least possible time.
2) The voltage fluctuation at all the consumers' terminals should be within ±5% of the declared voltage.
3) The system must work efficiently.
4) The insulation resistance of the system is to be extremely high to prevent leakage.
5) The system should be economical, considering the installation cost, maintaining cost, and operation cost.
6) The system design should consider future expansion due to load growth.

2.6 Classification of Distribution System

Electrical distribution system can be classified in many ways. One way is by the current type. There are two type of electrical distribution system, (1) AC distribution system, (2) DC distribution system. Distribution system can also be classified based on the type of construction of the distribution system, (1) overhead distribution systems and (2) underground distribution system. Overhead distribution system is often preferred for its lower cost, however if overhead system is impractical, underground distribution system will be used instead.[4-5]

2.6.1 DC Distribution system

DC distribution system is divided into two system; high voltage (primary distribution) and low voltage (secondary distribution).

Primary Distribution System: Generating stations transmit electrical power to various substations using transmission lines at high level voltage ranging from 33kV to 220kV. At the substations, the voltage is stepped down to 11kV or 6.6kV or 3.3kV. Electrical power is then delivered to other substations for distribution or to the bulk supply of consumers. This system is called high voltage or primary distribution system. The selection of voltage level depends on the amount of power to be conveyed and the distances of the receiving substations.

Secondary Distribution System: The voltage level at secondary distribution system is stepped down to 400V. Substations of secondary distribution system deliver electrical power to the consumers.

DC distribution system can also be divided by the system's network. There are (1) radial, (2) parallel, (3) ring, and (4) interconnected distribution system network. Figure 2 to Figure 5 shows all the distribution systems stated earlier.

Figure 2 DC radial distribution system

Figure 3 DC parallel distribution system

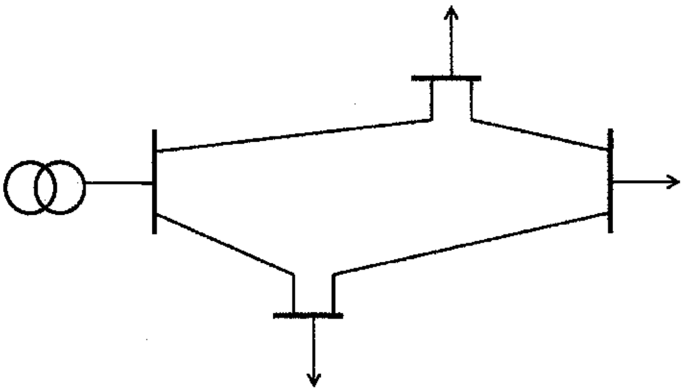

Figure 4 DC ring distribution system

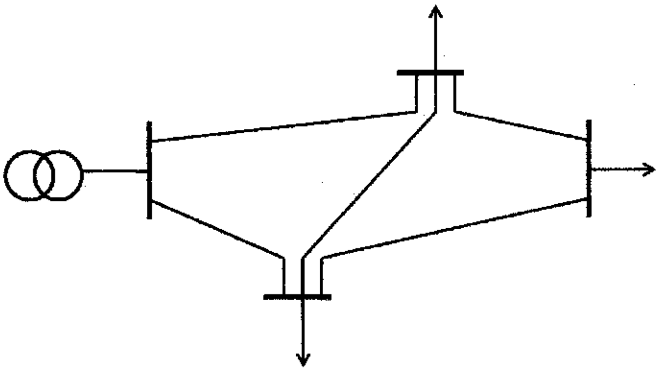

Figure 5 DC interconnected distribution system

Radial network is the simplest and has the lowest cost. However, radial distribution network does not provide reliability in its service. Parallel network provides better reliability of power supply because the power can be supplied to the consumers via different routes. Ring network gives option for scattered substations or consumers. Interconnected network is an improved ring system providing better reliability of delivering power to substations and consumers.

2.6.2 AC Distribution system

AC distribution system is divided into two system; high voltage (primary distribution) and low voltage (secondary distribution).[4-5]

Primary Distribution System

Primary distribution system is carried out by 3-phase, 3-wire system. The electrical power generated at the generation station is transmitted via transmission lines at high voltages ranging from 33kV to 400kV to substations located around the city. At these substations, the voltage is stepped down to 11kV, 6.6kV or 3.3kV by power transformer of the primary distribution system. Primary distribution system can be classified as follows:

1) Radial System: Figure 6 shows a radial distribution system. Transmission line supplies the primary distribution system feeders. Distribution transformers of substations step down the voltage to distribution voltage to supply various loads through distributors. This shows that radial distribution system is one of secondary distribution system. Primary feeder voltage commonly at 11kV and 3.3 kV. The secondary distribution voltage at the consumers side is 415/240 V.

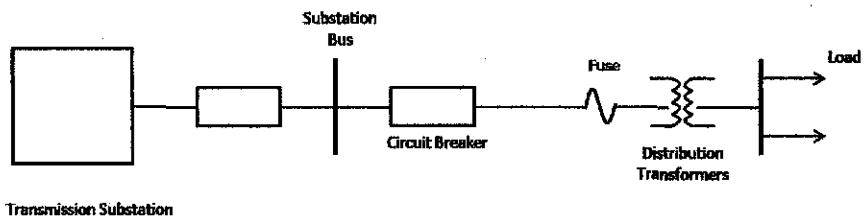

Figure 6 AC radial distribution system

2) Parallel or Loop System: Parallel system consists of two or more radial feeders from the same secondary substations in parallel. Each feeder capable of supplying the entire load. However, the feeders share the same amount of total load at normal conditions. Even though parallel system is expensive, but it offers greater reliability as one feeder can deliver the whole load if another feeder is out of service. Interruption time is short to transfer the load from the faulty feeder to the healthy one manually or automatically. Parallel system is preferred when the loads demand continuity on power supply.

Loop feeder system has two or more radial feeders from the same or different secondary substations laid on different routes of load areas. The feeders are connected together through normally open switching devices called the ring main feeder. Loop feeder system offers the most reliable power supply and provides better voltage regulation and less power loss. This system requires large amount of investment as the continuity of supply is the main priority. Feeders and loop components are designed to have sufficient reserve capacity to handle the load that will possibly be transferred under abnormal conditions. Figure 7 shows the Parallel or loop system.

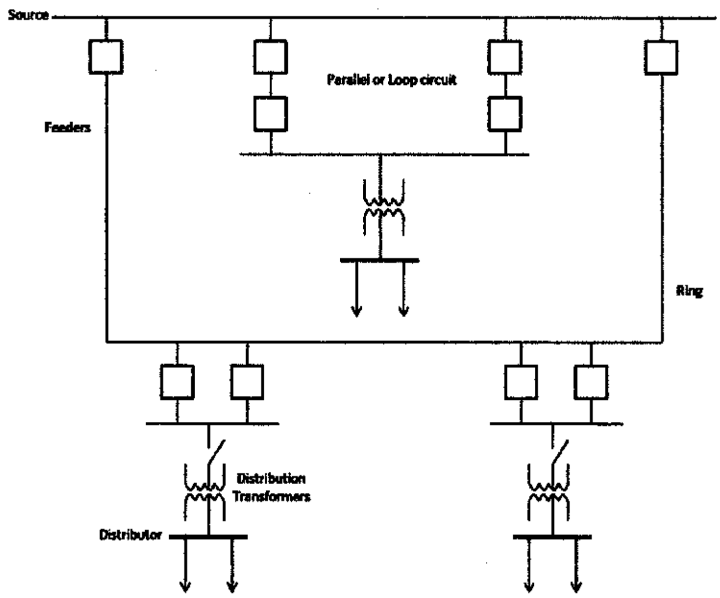

Figure 7 AC parallel or loop distribution system

3) Grid System: Grid system is often used for large distribution areas with large loads where the system needs to be able to supply power continuously and with better reliability. The grid system is shown in Figure 8. A grid distribution system is also used for heavy loads in the case of small crowded commercial areas. Grid distribution system offers maximum possible flexibility and reliability of supplying power continuously. Customers gain better voltage regulation and less possible outages. The overall size of grid distribution system is smaller compared to radial distribution system. More importantly, shifting loads or extension of loads can be executed with minimum changes to the grid distribution system compared to other type of distribution system. No extensive reconnections or changes are required.

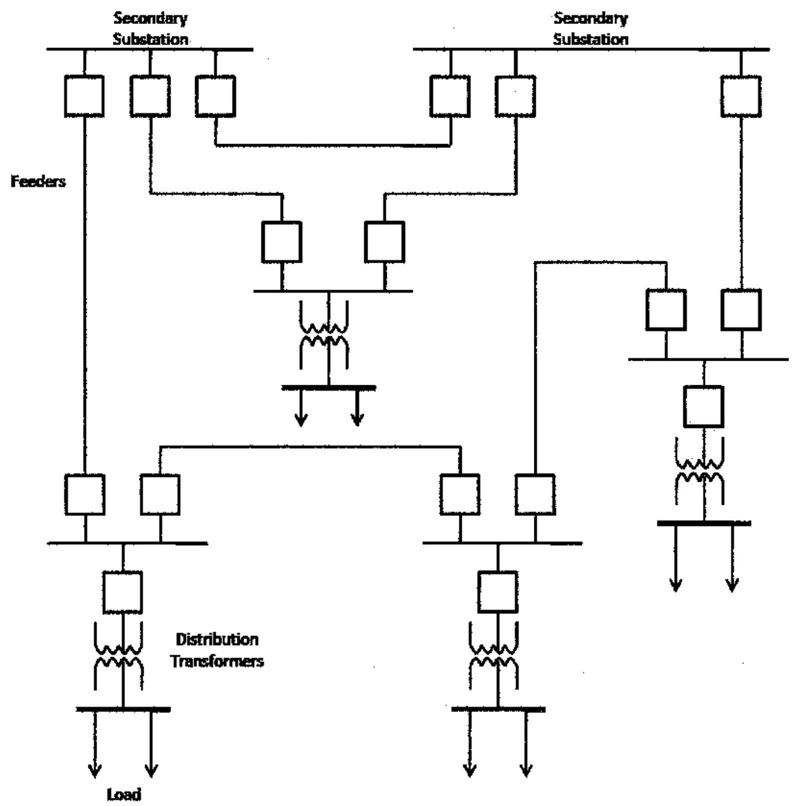

Figure 8 AC grid or network distribution system

Secondary Distribution System

Secondary Distribution System in AC distribution system includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to the consumer. It employs 400/230 V, 3-phase system. The primary distribution circuit delivers power to various sub-stations, called distribution substations. The substations are usually located near the consumers' locations and have step-down transformers. At each distribution substation, the voltage is stepped down to 400 V and the power is delivered by 3-phase, 4-wie AC system. The voltage limit for the type of voltage level is shown in table 2.1[6].

Table 1 Voltage limit for three voltage levels

CLASS	SYSTEM VOLTAGE NOMINAL RMS	PERMISSIBLE HIGHEST SYSTEM VOLTAGE RMS	PERMISSIBLE LOWEST SYSTEM VOLTAGE RMS
LOW VOLTAGE(1 PHASE)	230 V	264 V	200 V
LOW VOLTAGE(3 PHASE)	400 V	457 V	347 V
MEDIUM VOLTAGE(3 PHASE)	400 V	457 v	347 V
	3.3 kV	3.6 kV	3 kV
	6.6 Kv	7.2 kV	6 kV
	11 kV	12 kV	10.5 kV
	22 kV	24 kV	20 kV
	33 kV	36 kV	30 kV
HIGH VOLTAGE(3 PHASE)	66 kV	72.5 kV	60 kV

2.7 Design Considerations

The distribution system should be designed to be economically efficient and obeying to one's country Electricity Rules and Regulations.

Beside the two, voltage drop and current rating of the system is significantly important in the designing process. The size or the cross sectional area of the feeder is determined depending on the current running through the feeder and the economical aspect e.g. the cost of the conductor material and power losses. Voltage drop is not that important in designing feeders because consumers do not tap-off from feeders, plus the receiving end voltage can be stepped-up to desired level and be kept within the allowable limits [5].

2.8 Determination of Size of Conductors for Feeders and Distributors

In practice, Aluminium Conductor Steel Reinforced (ACSR) conductors are usually employed for distribution systems for both feeders and distributors. The conductor size of a feeder is determined based on the current carrying capacity and overall economy. The current carrying capacity of a conductor depends on the conductor losses and surroundings. The current carrying capacity is usually determined for a maximum operation temperature of 75 degree Celsius. After the size of the conductor has been determined, the voltage drop in the feeder should be checked to not be out from the range of regulating equipment. If the voltage drop is too high, the conductor size is changed to the next higher standard value till the voltage drop in the feeder is in the allowable range [7].

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The procedure identification flow is shown in Figure 9.

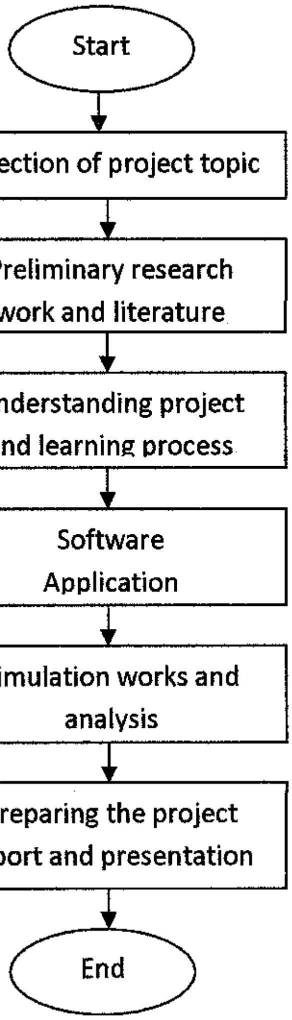

Figure 9 Procedure identification flow of the project

In the beginning of the semester, the titles for the Final Year Project had to be chosen or proposed. After the project title was chosen or approved, preliminary research work and literature review was done on the project title. The next task was to understand more regarding the project and learn from the literature reviews and researches. After understanding about the project, the actual algorithms and coding are done. Next step was to simulate the process of the project. The last step of the procedure is to prepare the project report and presentation.

3.2 Tools and Equipments Required

Software Requirement

i. MATLAB

ii. Simulink

3.3 Process Flow

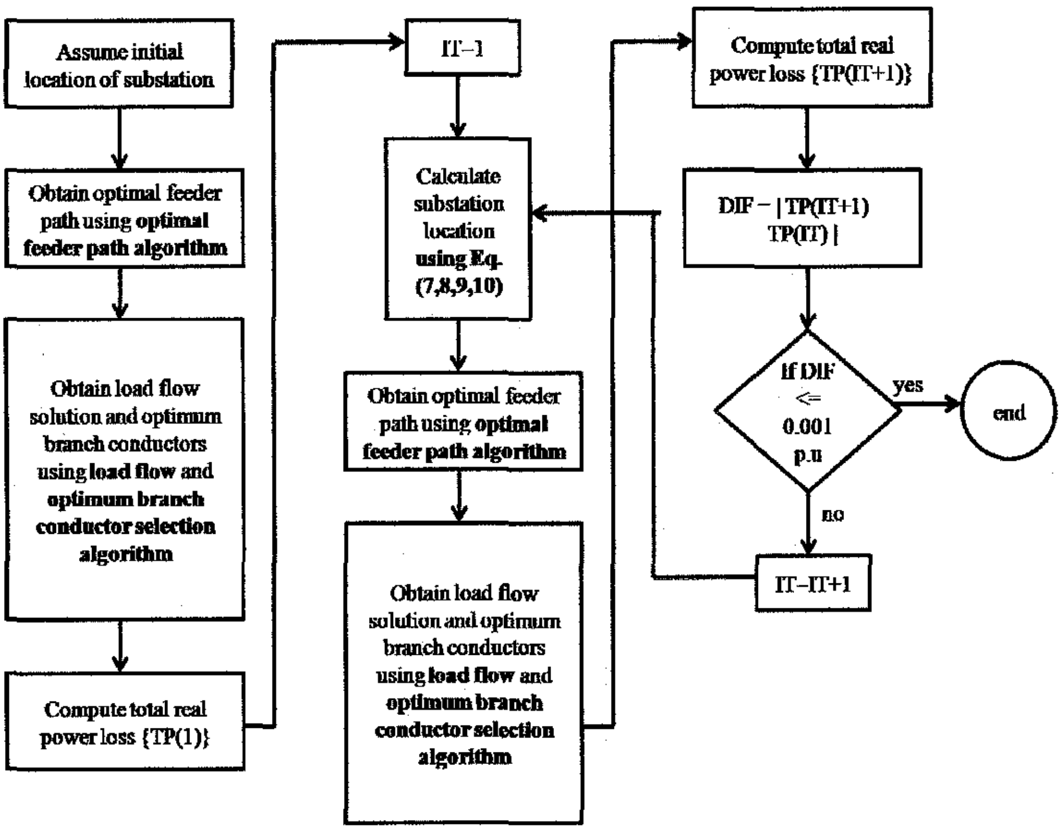

Figure 10 Distribution system planning process flow

When designing a distribution system, an assumption is made on the initial location of the substation to be at the centre of the nodes area. From this initial guess, optimal feeder path algorithm is performed to design the connection between the substation and all the nodes in the system. Once the connection of the system is established, load flow analysis is performed on the system to compute the power loss of all branches considering four types of Aluminium Conductor Steel Reinforced (ACSR) conductor with code name Squirrel, Weasel, Rabbit, and Raccoon. (Refer to APPENDIX B for conductor data sheet)

The branch conductor size is then selected based on the objective function of optimal branch conductor selection algorithm. When the conductor sizes of all the branches have been selected, the total power loss of the system is computed.

The new substation location can be calculated using Optimal Location of Substation Algorithm which will be discussed in next section. The new location of substation will be used to complete the second iteration of the designing process. At this stage, there will be two different designs with different power losses. The difference between the power losses of first and second iteration is computed and compared with the tolerance value. If the difference is higher than the tolerance value, another iteration of the whole process will be computed until the difference of total power loss between the later and current system is less than the tolerance value. The location of the substation is finalized then, along with the nodes connections and conductor size of all the branches of the system.

3.4 Optimal Feeder Path Algorithm

Optimal feeder path algorithm is used to design the connection between the substation and all the nodes in the system. In designing the connection, the investment cost is considered, and since the investment cost is directly proportional to the total length of the connection, by minimizing the total length of the connection, the lowest cost of the connection can be designed. For the project, three types of feeder is considered, which are single feeder, two feeders, and three feeders [8].

3.4.1 Single Feeder

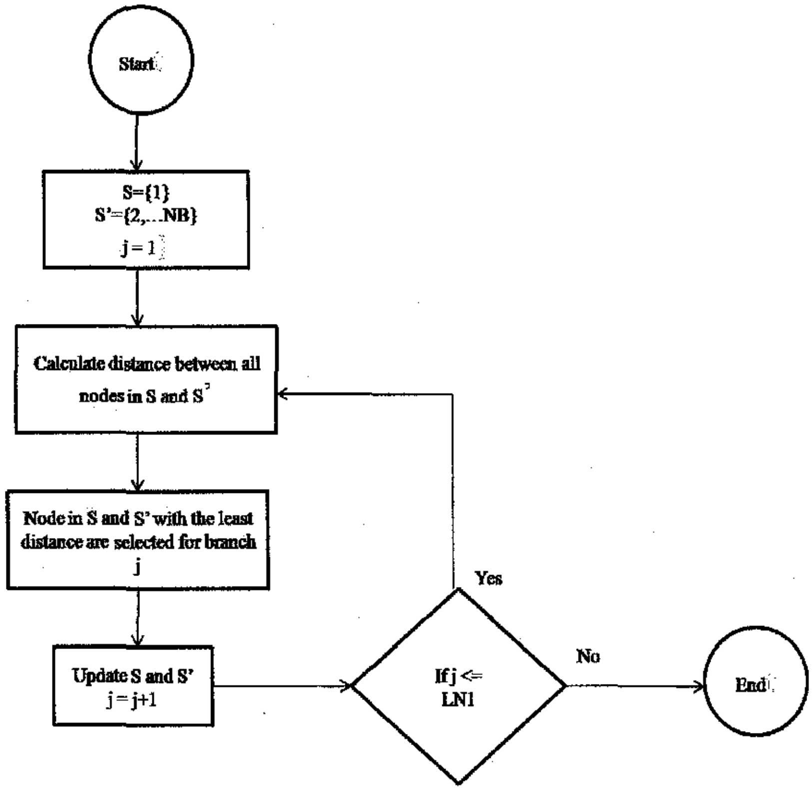

Figure 11 Single feeder optimal feeder path algorithm flowchart

For single feeder path, it is assumed that only one feeder emerges from the substation. The set of connected nodes, S for the first branch, j contains only the substation, numbered 1. The set of unconnected nodes, S' for the first branch contains all the other nodes, i = 2...NB (total number of nodes). The distance between all the nodes in S and S' is computed. The nodes in S and S' with minimum distance is selected to be the first branch. The set of nodes in S and S' is updated and the iteration continues until j is more than LN1 (total number of branch, LN1 = NB -1).

3.4.2 Two Feeder

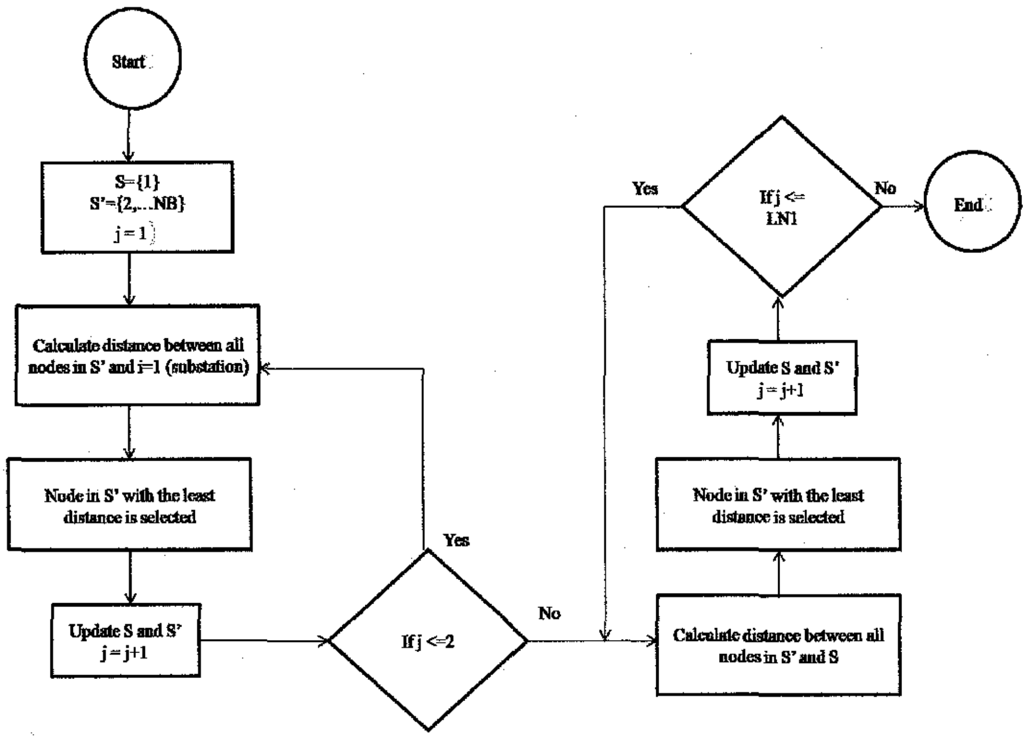

Figure 12 Two feeders optimal feeder path algorithm flowchart

For two feeder case, it is assumed that only two feeders emerge from the new substations. For the first two branches, (j=1, 2), two nodes from S' with the least distance are selected as the receiving end node of the branch 1 and 2. The set of nodes in S and S' is updated. From branch j=3 until j=LN1, the distance between all nodes in S and S' is computed. The node with the least distance is selected as the receiving end node of branch j. The set of nodes in S and S' is updated and the iteration will continue to select the next receiving node of branch j until all the branches have been computed.

3.4.3 Three Feeder

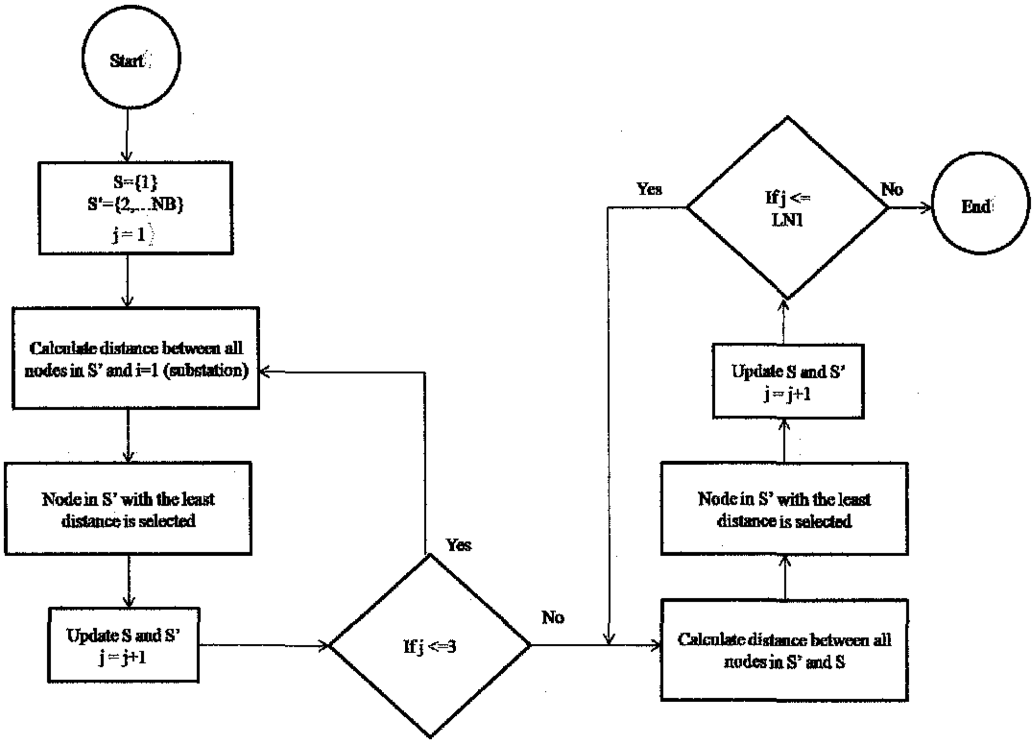

Figure 13 Three feeders optimal feeder path algorithm flowchart

For three feeder case, it is assumed that only three feeders emerge from the new substations. For the first three branches, (j=1, 2, 3), three nodes from S' with the least distance are selected as the receiving end node of the branch 1 and 2. The set of nodes in S and S' is updated. From branch j=4 until j=LN1, the distance between all nodes in S and S' is computed. The node with the least distance is selected as the receiving end node of branch j. The set of nodes in S and S' is updated and the iteration will continue to select the next receiving node of branch j until all the branches have been computed.

Therefore, there are three separate ways of designing electrical distribution system in this project.

3.5 Load Flow Analysis and Optimal Branch Conductor Algorithm

Load flow analysis is an analysis done to evaluate the distribution system. Voltage of all nodes, current and power losses along all branches, and total real and reactive power losses can be computed. All these data are used to select the conductor size of the branch using optimal branch conductor algorithm which will be discussed in details later.

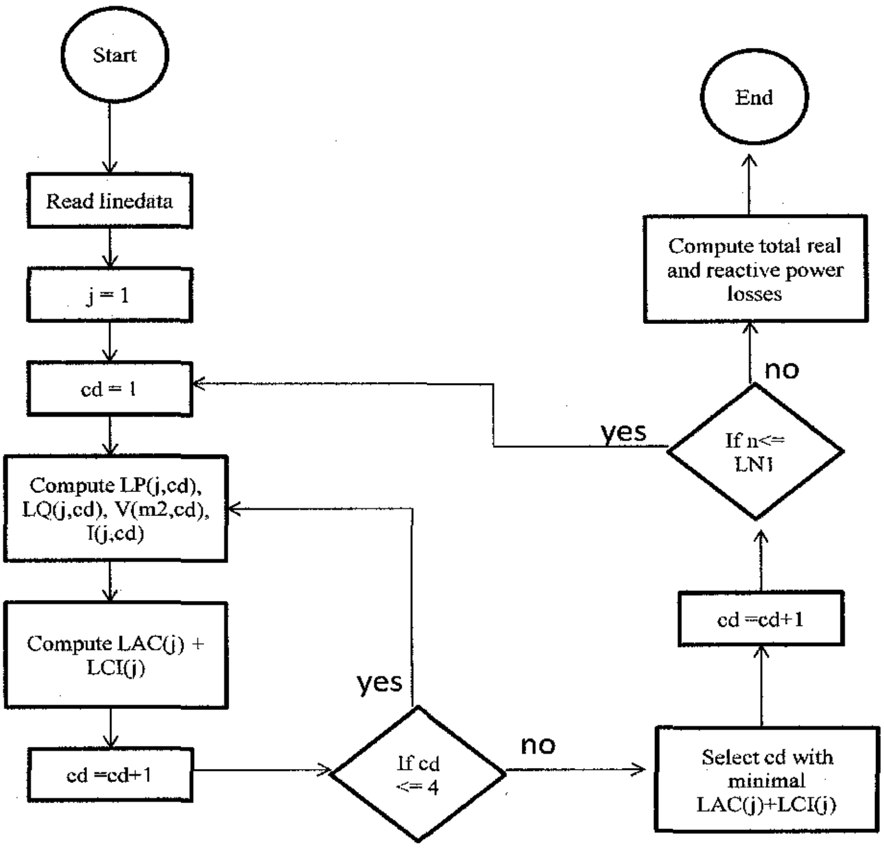

Figure 14 Load flow and optimal branch conductor selection algorithm flowchart

For load flow analysis and selecting conductor size, four ACSR conductor types, cd with the code named (1)Squirrel, (2)Weasel, (3)Rabbit, and (4)Raccoon are considered in the simulation. The algorithm is to calculate the voltage of receiving end node, V(m2,cd), current along branch j, I(j,cd), and real and reactive power losses along branch j, LP(j,cd) and LQ(j,cd). Then the objective function, LAC (j,cd) for selecting the conductor size is computed. Conductor type with the least LAC (j,cd) is selected as the conductor for branch j. Calculation is continued until all the branches are solved. Total real and reactive power losses are then computed.

3.5.1 Modified Load Flow Method

In this simulation, modified load flow method is used to perform load flow analysis. Initially, real and reactive power loss for all the branches are considered 0.0 p.u, and the voltage of all the nodes are considered 1.0 p.u. Consider single line diagram of 15-bus system shown in Figure 15, Figure 16 represents the electrical equivalent of figure 15 [9].

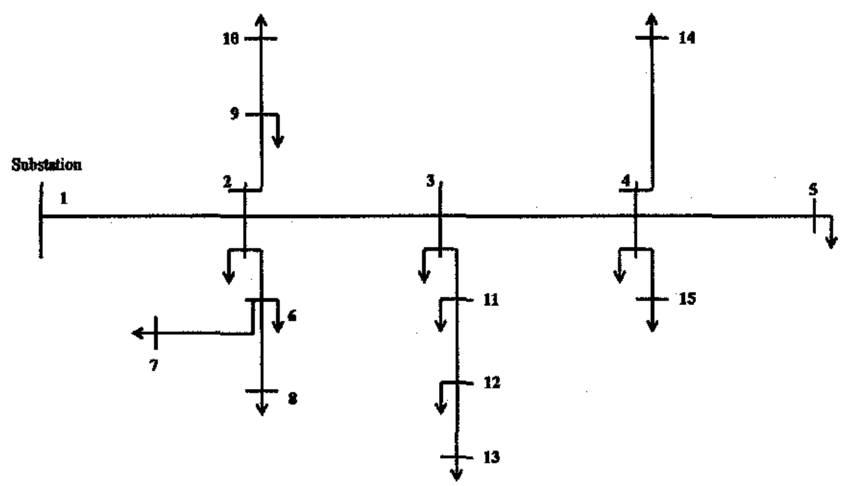

Figure 15 Single line diagram of 15 bus distribution system

Table 2 Linedata for Figure 15

Branch number (j)	**Sending node IS(j)**	**Receiving node IR(j)**
1	1	2
2	2	3
3	3	4
4	4	5
5	2	9
6	9	10
7	2	6
8	6	7
9	6	8
10	3	11
11	11	12
12	12	13
13	4	14
14	4	15

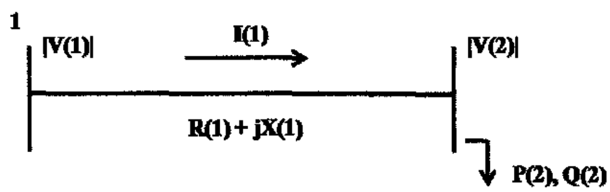

Figure 16 Electrical equivalent of Figure 3.7

$$I(1) = \left(|V(1)|\angle\delta(1) - |V(2)|\angle\delta(2)\right) / R(1) + jX(1) \qquad (1)$$

$$P(2) - jQ(2) = V(2) * I(1) \qquad (2)$$

$$|V(2)| = \{[(P(2)R(1) + Q(2)X(1) - 0.5|V(1)|^2)^2 - (R(1)^2 + X(1)^2)(P(2)^2 + Q(2)^2)]^{0.5} - (P(2)R(1) + Q(2)X(1) - 0.5|V(1)|)\}^{0.5} \quad (3)$$

From figure 3.8, the above equation (1) and (2) are obtained. Equation (3) can be derived from equation (1) and (2). (For details, refer to APPENDIX C). Where P (2) and Q (2) are total real and reactive power loads fed through node 2. Equation (3) can be generalized in the form of:

$$|V(m2)| = [B(j) - A(j)]^{0.5} \quad (4)$$

$$A(j) = P(m2) * R(j) + Q(m2) * X(j) - 0.5|V(m2)|^2 \quad (5)$$

$$B(j) = \{A(j)^2 - [R(i)^2 + X(j)^2] * [P(m2)^2 + Q(m2)^2]\}^{0.5} \quad (6)$$

Real and reactive power losses in branch 1 are:

$$LP(1) = \frac{R(1) * [P(2)^2 + Q(2)^2]}{|V(2)|^2} \quad (7)$$

$$LQ(1) = \frac{X(1) * [P(2)^2 + Q(2)^2]}{|V(2)|^2} \quad (8)$$

In generalized form, real and reactive power losses are:

$$LP(j) = \frac{R(j) * [P(m2)^2 + Q(m2)^2]}{|V(m2)|^2} \tag{9}$$

$$LQ(j) = \frac{X(j) * [P(m2)^2 + Q(m2)^2]}{|V(m2)|^2} \tag{10}$$

Modified load flow method used in this project can be divided in two parts, (1) the identification of nodes and branches beyond a particular node, and (2) load flow calculation.

3.5.1.1 Identification of nodes and branches beyond a particular node

This subsection will discuss the methodology of identifying the nodes and branches beyond a particular node. The identification process is important to find the exact load feeding through a particular node. Several more variables that are used particularly for this part of the algorithm are introduced in addition to the variables that are introduced earlier in this report.

ip	node count (identifies number of nodes beyond a particular node)
IK(ip)	node identifier(helps to identify the sending and receiving node which are given in the ith branch of linedata)
LL(ip)	stores sending node of ith row of linedata
KK(ip)	stores receiving node of ith row of linedata
N(j)	total number of nodes beyond node IR(j) plus 1(node IR(j) itself)
IB(j,ip+1)	sending node
IE(j,ip+1)	receiving node

By introducing variables above, IB (j, ip+1) and IE (j, ip+1) will be further explained. Refer to Figure 15, consider the first branch i.e j = 1, the receiving node of branch j is i = 2 (see Table 3.1). Therefore IB (1, ip+1) and IE (1,ip+1) will help to identify all the branches and nodes beyond node 2 and node 2 itself. Figure 17 shows the flowchart for identification of nodes and branches beyond a particular node.

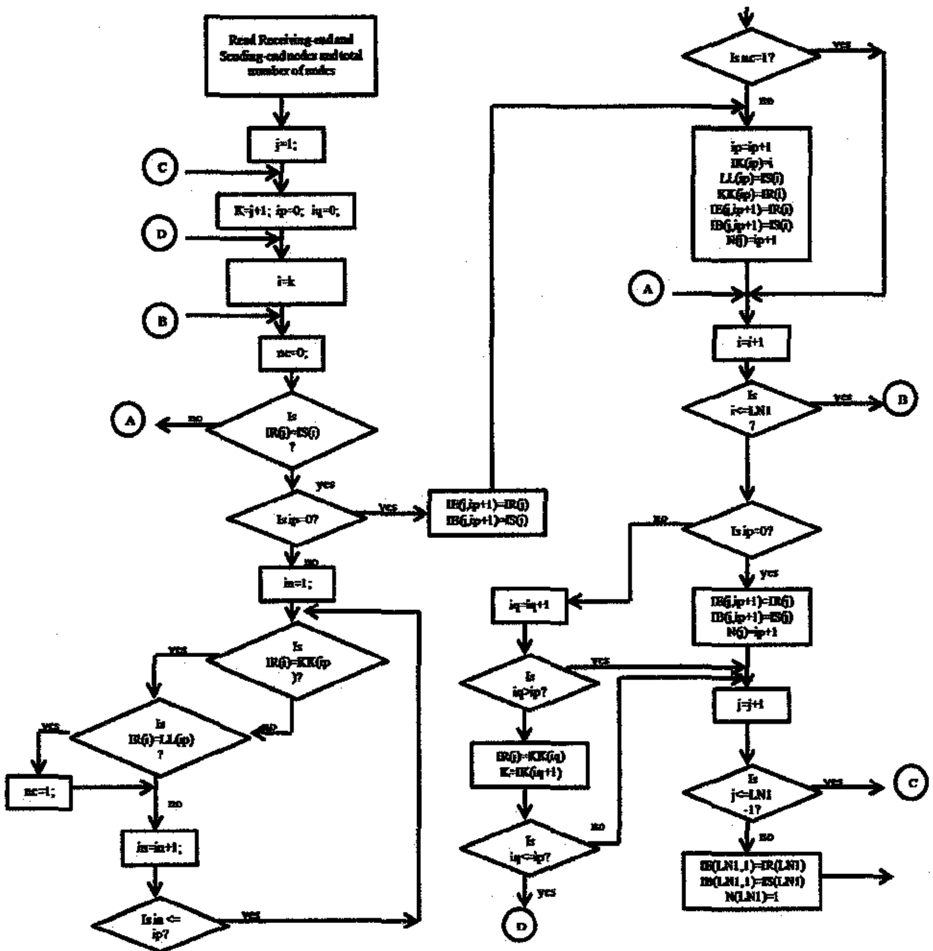

Figure 17 Flowchart for identification of nodes and branches beyond a particular node

3.5.1.2 Load Flow Calculation

Once all the nodes and branches are identified, it is very easy to calculate. voltage of all the nodes using equation (4), (5), and (6). In this algorithm, the exact load feeding through all the receiving nodes and the voltage magnitude of all nodes are to be computed. The branch current, real and reactive losses of all the branches and the total real and reactive power losses can then be computed. Figure 18 shows the flowchart for load flow calculation

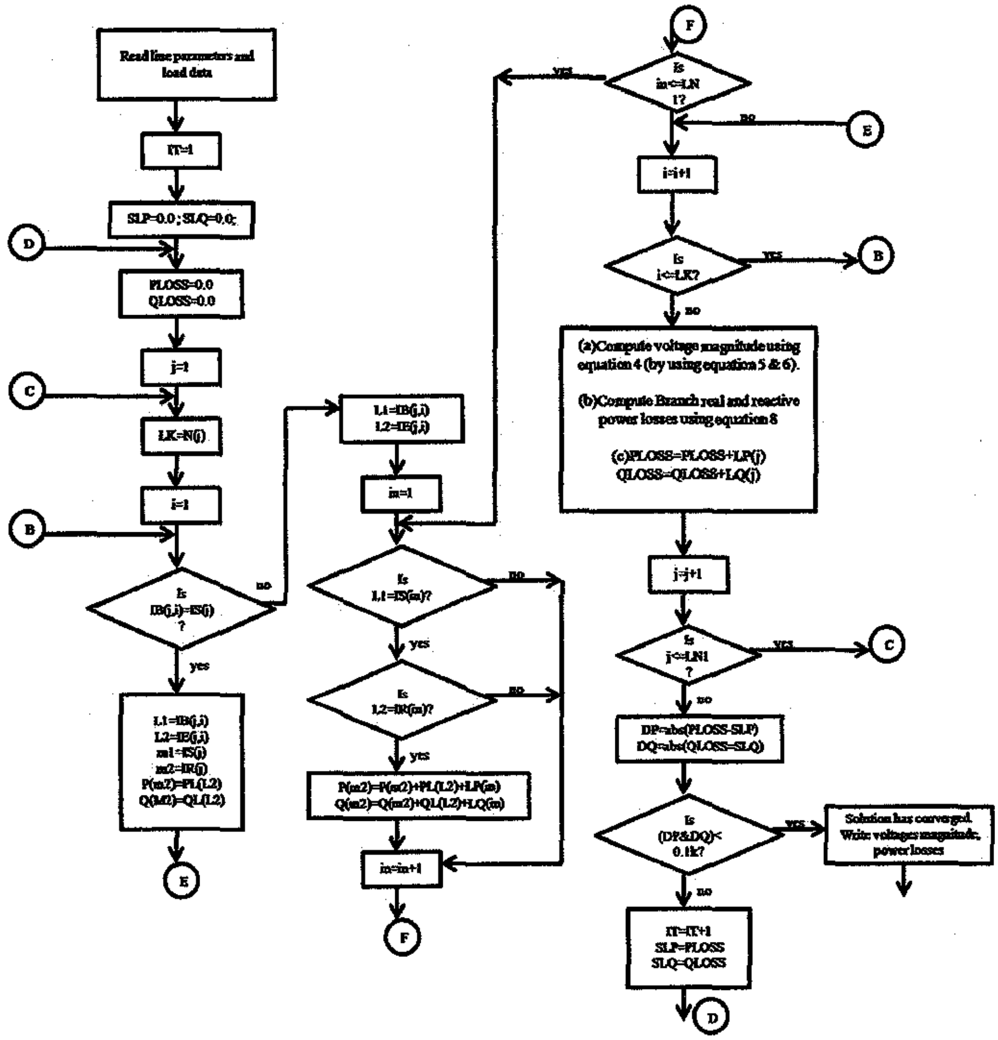

Figure 18 Flowchart for load flow calculation

3.5.2 *Optimal Branch Conductor Selection Algorithm*

Selecting branch conductor size is important in distribution system planning. The aim is to design a feeder which minimizes an objective function, which is the sum of capital investment and capitalized energy loss costs for the feeders. The conductor selected must also maintain an acceptable voltage level [10].

The levelized annual cost for real power loss in branch j can be computed by:

$$LAC(j) = Kp * LP(j) + LP(j) * KE * T * Lsf \tag{11}$$

Where LP (j) is the real power loss in branch j, Kp is levelized annual demand cost of losses (MYR/kW), KE is energy cost of losses (MYR/kWh), T is 8760h, and Lsf is loss factor.

The levelized annual cost of capital investment for branch j is:

$$LCI(j) = a * A(j) * C * LEN(j) \tag{12}$$

Where C is the cost of the line (MYR/mm^2 per km), A (j) is the size of the conductor (mm^2), LEN (j) is the length of branch j (km), and a is the current rating of the conductor (A).

Hence, the objective function of branch j is the sum of *LAC(j) and LCI(j)*.

In selecting the conductor type, several constraints must be satisfied:

i. Voltage at every node in the distribution system must be above the minimum voltage level, V_{min}.

ii. Current flowing through branch j with cd type of conductor must be less than the maximum current carrying capacity of cd type conductor.

3.6 Optimum Location of Substation

Optimal location of substation is computed through iterative algorithm. Substation is always chosen as node 1. Total reactive power loss, Q (i) for node i = 2...NB is available from the load flow analysis and branch conductor selection algorithm. The location of substation [x (1), y (1)] can be computed using the following iterative algorithm [8]:

$$x(s) = \frac{\sum_{i=1}^{NB} W(i) * x(i)}{\sum_{i=1}^{NB} W(i)} \tag{12}$$

$$y(s) = \frac{\sum_{i=1}^{NB} W(i) * y(i)}{\sum_{i=1}^{NB} W(i)} \tag{13}$$

Where x(i),y(i) are the coordinates of the load point for i=2….NB.

$$W(i) = \frac{Q(i) * R(KT)}{|V(i)|^2 * Ds(i)} \tag{14}$$

KT=K (i-1), stores optimum type of branch conductor for i=2…NB.

$$Ds(i) = \{(x(s) - x(i))^2 + (y(s) - y(i))^2\}^2 \tag{15}$$

3.7 Simulation on 54 bus and 21 bus system

Based on the algorithms described in sections before, the planning process of electrical distribution system is simulated on 54 bus system and 21 bus system. The bus data for both of the system can be referred to APPENDIX D and APPENDIX E. The simulation is done on MATLAB software, and the complete source code for the planning process can be referred to APPENDIX F.

There are several variables in the source code needs to be changed for simulation on both system with regard to single feeder, two feeders, and three feeders system.

To simulate the planning process on 54 bus system, set the variable busdata = busdata54() in line 4 (refer to APPENDIX F), as shown in figure a. For 21 bus system, the variable busdata is changed to busdata21() in line 4(refer APPENDIX F), as shown in Figure 19 and Figure 20.

```
%================================================================
%declaration of fix variable
%================================================================
busdata = busdata54();
NB=max(busdata(:,1));%total number of nodes in the system
LN1=NB-1;%total number of branches in the system
basekva=100000;%base VA value
basevolt=11000;%base voltage value
basereactance=basevolt^2/basekva;%base reactance value
condctype=condctype4();%call conductor data sheet function
DIFFx=0.1;
```

Figure 19 Source code for 54 bus system (partial)

```
%================================================================
%declaration of fix variable
%================================================================
busdata = busdata21();
NB=max(busdata(:,1));%total number of nodes in the system
LN1=NB-1;%total number of branches in the system
basekva=100000;%base VA value
basevolt=11000;%base voltage value
basereactance=basevolt^2/basekva;%base reactance value
condctype=condctype4();%call conductor data sheet function
DIFFx=0.1;
```

Figure 20 Source code for 21 bus system (partial)

Planning process can be done based on three network configurations which are single feeder, two feeders, and three feeders. In line 28 (refer to APPENDIX F), change the variable feeder to the value of the feeder intended, (1) for single feeder, (2) for two feeders, and (3) for three feeders. Figure 21 to Figure 23 shows the specific line in the source code for each of the planning design.

```
%declaration of variables used in OPTIMAL FEEDER PATH ALGORITHM
connodes=busdata(1,1:4);
unconnodes=busdata(2:NB,1:4);
CN=1;
UCN=NB-CN;
linedata=[];%declare linedata variables to store linedata of system designed
distance=0;%stores minimum distance in every iteration to be updated in linedata
doublesender=55;%initial value for doublesender
feeder=1;
```

Figure 21 Source code for single feeder design (partial)

```
%declaration of variables used in OPTIMAL FEEDER PATH ALGORITHM
connodes=busdata(1,1:4);
unconnodes=busdata(2:NB,1:4);
CN=1;
UCN=NB-CN;
linedata=[];%declare linedata variables to store linedata of system designed
distance=0;%stores minimum distance in every iteration to be updated in linedata
doublesender=55;%initial value for doublesender
feeder=2;
```

Figure 22 Source code for two feeders design (partial)

```
%declaration of variables used in OPTIMAL FEEDER PATH ALGORITHM
connodes=busdata(1,1:4);
unconnodes=busdata(2:NB,1:4);
CN=1;
UCN=NB-CN;
linedata=[];%declare linedata variables to store linedata of system designed
distance=0;%stores minimum distance in every iteration to be updated in linedata
doublesender=55;%initial value for doublesender
feeder=3;
```

Figure 23 Source code for three feeders design (partial)

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

In this section, we summarize the results of the work done so far in this project.

4.1.1 54 bus Electrical Distribution System Design

Figure 25 to Figure 27 below show the design for single feeder, two feeders, and three feeders distribution system based on Optimal Feeder Path Algorithm for 54 nodes system. Node numbered 1 in both figure represents the substation location.

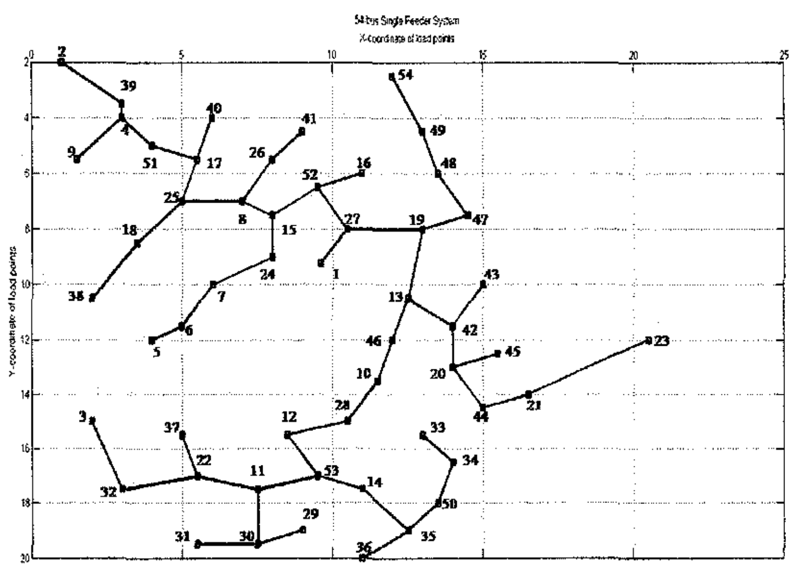

Figure 24 Single feeder distribution system network (54 nodes)

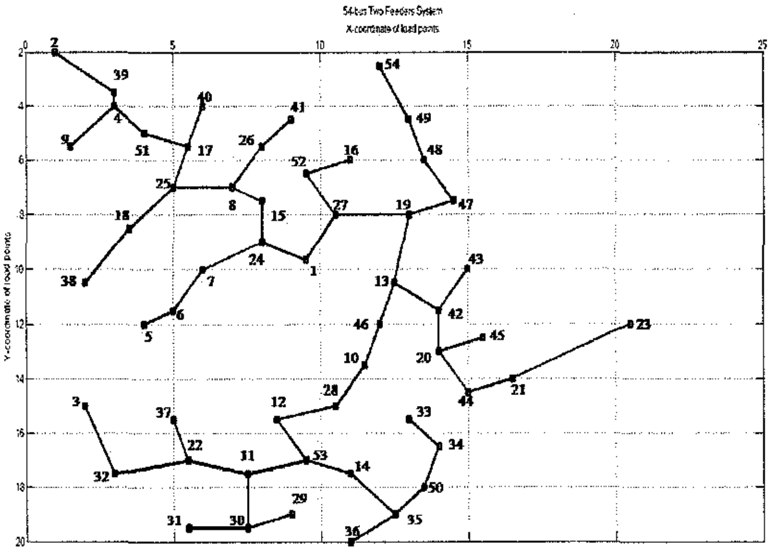

Figure 25 Two feeders distribution system network (54 nodes)

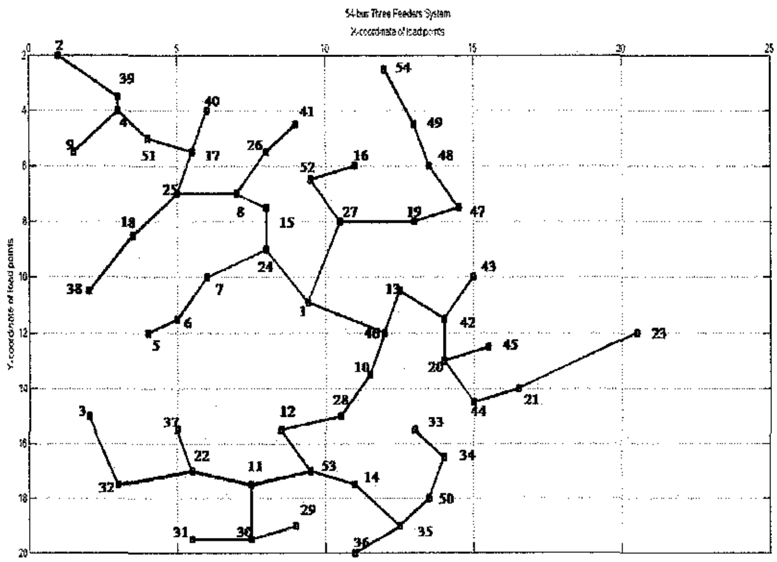

Figure 26 Three feeders distribution system network (54 nodes)

Table 3 shows the exact location of substation for single feeder, two feeders, and three feeders distribution system.

Table 3 Substation coordinates for three designs of 54 bus system

	x-coordinate	**y-coordinate**
Single feeder	9.6063	9.2267
Two feeders	9.5248	9.6459
Three feeders	9.4163	10.9042

4.1.2 54 bus Electrical Distribution System Analysis

Table 4 to Table 6 show the result from load flow analysis done to 54 bus single feeder, two feeders, and three feeders distribution system. The tables show the branch number, sending node, receiving node, distance in kilometer, voltage of receiving node, conductor type for branch j, resistance and reactance for branch j in p.u, and real and reactive power loss along branch j. For conductor type, 1 represents Squirrel, 2 for Weasel, 3 for Rabbit, and 4 for Raccon.

Table 4 Linedata for single feeder distribution system (54 nodes)

j	**IS**	**IR**	**Dist(km)**	**V(IR)**	**cd**	**R(p.u)**	**X(p.u)**	**LP(pu)**	**LQ(pu)**
1	1	27	1.51772	0.98724	4	0.00045	0.00036	0.22201	0.17479
2	27	52	1.80278	0.96225	2	0.00135	0.00047	0.12501	0.04323
3	52	16	1.58114	0.94592	1	0.00179	0.00043	0.00013	0.00003
4	52	15	1.80278	0.94991	2	0.00135	0.00047	0.11716	0.04052
5	15	8	1.11803	0.94518	2	0.00084	0.00029	0.02789	0.00965
6	15	24	1.50000	0.92406	1	0.00170	0.00041	0.01515	0.00362
7	8	26	1.80278	0.91934	1	0.00204	0.00049	0.00377	0.00090
8	26	41	1.41421	0.91895	1	0.00160	0.00038	0.00012	0.00003

9	8	25	2.00000	0.91353	1	0.00226	0.00054	0.03715	0.00887
10	25	17	1.58114	0.90988	1	0.00179	0.00043	0.00900	0.00215
11	17	40	1.58114	0.90944	1	0.00179	0.00043	0.00014	0.00003
12	17	51	1.58114	0.90696	1	0.00179	0.00043	0.00578	0.00138
13	51	4	1.41421	0.90474	1	0.00160	0.00038	0.00373	0.00089
14	4	39	0.50000	0.90424	1	0.00057	0.00014	0.00054	0.00013
15	25	18	2.12132	0.91195	1	0.00240	0.00057	0.00126	0.00030
16	4	9	2.12132	0.90414	1	0.00240	0.00057	0.00018	0.00004
17	24	7	2.23607	0.91966	1	0.00253	0.00060	0.00927	0.00221
18	7	6	1.80278	0.91737	1	0.00204	0.00049	0.00310	0.00074
19	6	5	1.11803	0.91675	1	0.00127	0.00030	0.00038	0.00009
20	27	19	2.50000	0.96760	3	0.00112	0.00061	0.17486	0.09564
21	19	47	1.58114	0.92831	1	0.00179	0.00043	0.00493	0.00118
22	47	48	1.80278	0.92649	1	0.00204	0.00049	0.00197	0.00047
23	48	49	1.58114	0.92533	1	0.00179	0.00043	0.00091	0.00022
24	49	54	2.23607	0.92409	1	0.00253	0.00060	0.00074	0.00018
25	39	2	2.50000	0.90353	1	0.00283	0.00068	0.00022	0.00005
26	18	38	2.50000	0.91054	1	0.00283	0.00068	0.00085	0.00020
27	19	13	2.54951	0.93071	2	0.00191	0.00066	0.23797	0.08229
28	13	46	1.58114	0.92189	2	0.00119	0.00041	0.06841	0.02366
29	46	10	1.58114	0.91379	2	0.00119	0.00041	0.05766	0.01994
30	13	42	1.80278	0.92660	2	0.00135	0.00047	0.01307	0.00452
31	42	20	1.50000	0.92435	2	0.00113	0.00039	0.00466	0.00161
32	20	45	1.58114	0.92404	2	0.00119	0.00041	0.00009	0.00003
33	10	28	1.80278	0.90469	2	0.00135	0.00047	0.06374	0.02204
34	42	43	1.80278	0.92588	2	0.00135	0.00047	0.00039	0.00014
35	20	44	1.80278	0.92292	2	0.00135	0.00047	0.00159	0.00055
36	44	21	1.58114	0.92197	2	0.00119	0.00041	0.00079	0.00027
37	28	12	2.06155	0.93032	3	0.00093	0.00051	0.03485	0.01906
38	12	53	1.80278	0.92501	3	0.00081	0.00044	0.02819	0.01542
39	53	14	1.58114	0.92305	3	0.00071	0.00039	0.00437	0.00239
40	53	11	2.06155	0.92175	3	0.00093	0.00051	0.00928	0.00508
41	11	30	2.00000	0.92011	3	0.00090	0.00049	0.00242	0.00132
42	30	29	1.58114	0.91990	3	0.00071	0.00039	0.00005	0.00003
43	30	31	2.00000	0.91943	3	0.00090	0.00049	0.00042	0.00023
44	11	22	2.06155	0.92035	3	0.00093	0.00051	0.00171	0.00093
45	22	37	1.58114	0.91992	3	0.00071	0.00039	0.00021	0.00011
46	14	35	2.12132	0.92114	3	0.00095	0.00052	0.00309	0.00169
47	35	50	1.41421	0.92025	3	0.00063	0.00035	0.00101	0.00055
48	50	34	1.58114	0.91939	3	0.00071	0.00039	0.00084	0.00046
49	34	33	1.41421	0.91901	3	0.00063	0.00035	0.00019	0.00010
50	35	36	1.80278	0.92090	3	0.00081	0.00044	0.00006	0.00003
51	22	32	2.54951	0.91966	3	0.00114	0.00063	0.00034	0.00018

52	32	3	2.69258	0.91929	3	0.00121	0.00066	0.00009	0.00005
53	21	23	4.47214	0.92019	2	0.00336	0.00116	0.00099	0.00034

Table 5 Linedata for two feeders distribution system (54 nodes)

j	IS	IR	Dist(km)	V(IR)	cd	R(p.u)	X(p.u)	LP(pu)	LQ(pu)
1	1	24	1.65597	0.98912	2	0.00124	0.00043	0.09926	0.03432
2	1	27	1.91312	0.98744	3	0.00086	0.00047	0.14858	0.08127
3	24	15	1.50000	0.98230	2	0.00113	0.00039	0.04312	0.01491
4	15	8	1.11803	0.97772	2	0.00084	0.00029	0.02607	0.00901
5	27	52	1.80278	0.97289	1	0.00204	0.00049	0.00036	0.00009
6	52	16	1.58114	0.97247	1	0.00179	0.00043	0.00012	0.00003
7	8	26	1.80278	0.96619	1	0.00204	0.00049	0.00342	0.00082
8	26	41	1.41421	0.96581	1	0.00160	0.00038	0.00011	0.00003
9	8	25	2.00000	0.96066	1	0.00226	0.00054	0.03359	0.00802
10	25	17	1.58114	0.95719	1	0.00179	0.00043	0.00813	0.00194
11	17	40	1.58114	0.95677	1	0.00179	0.00043	0.00012	0.00003
12	17	51	1.58114	0.95442	1	0.00179	0.00043	0.00522	0.00125
13	51	4	1.41421	0.95231	1	0.00160	0.00038	0.00336	0.00080
14	4	39	0.50000	0.95183	1	0.00057	0.00014	0.00048	0.00012
15	25	18	2.12132	0.95916	1	0.00240	0.00057	0.00114	0.00027
16	4	9	2.12132	0.95174	1	0.00240	0.00057	0.00017	0.00004
17	24	7	2.23607	0.98056	1	0.00253	0.00060	0.00816	0.00195
18	7	6	1.80278	0.97842	1	0.00204	0.00049	0.00272	0.00065
19	6	5	1.11803	0.97783	1	0.00127	0.00030	0.00033	0.00008
20	27	19	2.50000	0.97193	3	0.00112	0.00061	0.17331	0.09479
21	19	47	1.58114	0.93783	1	0.00179	0.00043	0.00483	0.00115
22	47	48	1.80278	0.93603	1	0.00204	0.00049	0.00193	0.00046
23	48	49	1.58114	0.93488	1	0.00179	0.00043	0.00089	0.00021
24	49	54	2.23607	0.93365	1	0.00253	0.00060	0.00073	0.00017
25	39	2	2.50000	0.95116	1	0.00283	0.00068	0.00020	0.00005
26	18	38	2.50000	0.95782	1	0.00283	0.00068	0.00077	0.00018
27	19	13	2.54951	0.93741	2	0.00191	0.00066	0.23458	0.08112
28	13	46	1.58114	0.92864	2	0.00119	0.00041	0.06742	0.02331
29	46	10	1.58114	0.92060	2	0.00119	0.00041	0.05681	0.01964
30	13	42	1.80278	0.90458	1	0.00204	0.00049	0.02069	0.00494
31	42	20	1.50000	0.90137	1	0.00170	0.00041	0.00739	0.00176
32	20	45	1.58114	0.90092	1	0.00179	0.00043	0.00014	0.00003
33	10	28	1.80278	0.91158	2	0.00135	0.00047	0.06278	0.02171
34	42	43	1.80278	0.90356	1	0.00204	0.00049	0.00063	0.00015
35	20	44	1.80278	0.92967	2	0.00135	0.00047	0.00157	0.00054
36	44	21	1.58114	0.92873	2	0.00119	0.00041	0.00077	0.00027
37	28	12	2.06155	0.90198	2	0.00155	0.00053	0.06200	0.02144
38	12	53	1.80278	0.92954	3	0.00081	0.00044	0.02791	0.01527
39	53	14	1.58114	0.92759	3	0.00071	0.00039	0.00432	0.00237

40	53	11	2.06155	0.92629	3	0.00093	0.00051	0.00919	0.00503
41	11	30	2.00000	0.92466	3	0.00090	0.00049	0.00239	0.00131
42	30	29	1.58114	0.92445	3	0.00071	0.00039	0.00005	0.00003
43	30	31	2.00000	0.92398	3	0.00090	0.00049	0.00042	0.00023
44	11	22	2.06155	0.92490	3	0.00093	0.00051	0.00169	0.00092
45	22	37	1.58114	0.92448	3	0.00071	0.00039	0.00021	0.00011
46	14	35	2.12132	0.92569	3	0.00095	0.00052	0.00306	0.00167
47	35	50	1.41421	0.92480	3	0.00063	0.00035	0.00100	0.00055
48	50	34	1.58114	0.92395	3	0.00071	0.00039	0.00083	0.00045
49	34	33	1.41421	0.92357	3	0.00063	0.00035	0.00019	0.00010
50	35	36	1.80278	0.92545	3	0.00081	0.00044	0.00006	0.00003
51	22	32	2.54951	0.92421	3	0.00114	0.00063	0.00033	0.00018
52	32	3	2.69258	0.92385	3	0.00121	0.00066	0.00009	0.00005
53	21	23	4.47214	0.92696	2	0.00336	0.00116	0.00098	0.00034

Table 6 Three feeders distribution system linedata (54 bus)

j	IS	IR	Dist(km)	V(IR)	cd	R(p.u)	X(p.u)	LP(pu)	LQ(pu)
1	1	24	2.37316	0.98433	2	0.00178	0.00062	0.14363	0.04967
2	1	46	2.80648	0.97808	2	0.00211	0.00073	0.23719	0.08202
3	1	27	3.09982	0.99160	1	0.00351	0.00084	0.02431	0.00580
4	24	15	1.50000	0.97747	2	0.00113	0.00039	0.04355	0.01506
5	15	8	1.11803	0.97287	2	0.00084	0.00029	0.02633	0.00911
6	46	10	1.58114	0.97046	2	0.00119	0.00041	0.05112	0.01768
7	46	13	1.58114	0.96325	1	0.00179	0.00043	0.02204	0.00526
8	27	52	1.80278	0.99084	1	0.00204	0.00049	0.00035	0.00008
9	52	16	1.58114	0.99043	1	0.00179	0.00043	0.00011	0.00003
10	8	26	1.80278	0.95925	1	0.00204	0.00049	0.00347	0.00083
11	26	41	1.41421	0.95887	1	0.00160	0.00038	0.00011	0.00003
12	10	28	1.80278	0.96190	2	0.00135	0.00047	0.05638	0.01950
13	13	42	1.80278	0.95768	1	0.00204	0.00049	0.01846	0.00441
14	42	20	1.50000	0.95464	1	0.00170	0.00041	0.00659	0.00157
15	20	45	1.58114	0.95421	1	0.00179	0.00043	0.00012	0.00003
16	42	43	1.80278	0.95671	1	0.00204	0.00049	0.00056	0.00013
17	20	44	1.80278	0.95269	1	0.00204	0.00049	0.00225	0.00054
18	44	21	1.58114	0.95141	1	0.00179	0.00043	0.00111	0.00027
19	8	25	2.00000	0.95368	1	0.00226	0.00054	0.03408	0.00814
20	25	17	1.58114	0.95019	1	0.00179	0.00043	0.00825	0.00197
21	17	40	1.58114	0.94976	1	0.00179	0.00043	0.00012	0.00003
22	17	51	1.58114	0.94739	1	0.00179	0.00043	0.00530	0.00126
23	51	4	1.41421	0.94527	1	0.00160	0.00038	0.00341	0.00081
24	4	39	0.50000	0.94479	1	0.00057	0.00014	0.00049	0.00012
25	28	12	2.06155	0.95282	2	0.00155	0.00053	0.05556	0.01921

26	12	53	1.80278	0.94517	2	0.00135	0.00047	0.04514	0.01561
27	53	14	1.58114	0.91791	1	0.00179	0.00043	0.01114	0.00266
28	53	11	2.06155	0.91520	1	0.00233	0.00056	0.02376	0.00567
29	11	30	2.00000	0.91179	1	0.00226	0.00054	0.00621	0.00148
30	30	29	1.58114	0.91134	1	0.00179	0.00043	0.00013	0.00003
31	30	31	2.00000	0.91037	1	0.00226	0.00054	0.00108	0.00026
32	11	22	2.06155	0.91229	1	0.00233	0.00056	0.00438	0.00105
33	22	37	1.58114	0.91140	1	0.00179	0.00043	0.00054	0.00013
34	25	18	2.12132	0.95217	1	0.00240	0.00057	0.00115	0.00028
35	4	9	2.12132	0.94469	1	0.00240	0.00057	0.00017	0.00004
36	14	35	2.12132	0.91394	1	0.00240	0.00057	0.00792	0.00189
37	35	50	1.41421	0.91209	1	0.00160	0.00038	0.00259	0.00062
38	50	34	1.58114	0.91031	1	0.00179	0.00043	0.00216	0.00052
39	34	33	1.41421	0.90951	1	0.00160	0.00038	0.00048	0.00012
40	35	36	1.80278	0.91344	1	0.00204	0.00049	0.00015	0.00004
41	24	7	2.23607	0.97372	1	0.00253	0.00060	0.00827	0.00197
42	7	6	1.80278	0.97157	1	0.00204	0.00049	0.00276	0.00066
43	6	5	1.11803	0.97097	1	0.00127	0.00030	0.00034	0.00008
44	27	19	2.50000	0.98717	1	0.00283	0.00068	0.00839	0.00200
45	19	47	1.58114	0.98463	1	0.00179	0.00043	0.00438	0.00105
46	47	48	1.80278	0.98292	1	0.00204	0.00049	0.00175	0.00042
47	48	49	1.58114	0.98182	1	0.00179	0.00043	0.00081	0.00019
48	49	54	2.23607	0.98065	1	0.00253	0.00060	0.00066	0.00016
49	39	2	2.50000	0.94411	1	0.00283	0.00068	0.00020	0.00005
50	18	38	2.50000	0.95081	1	0.00283	0.00068	0.00078	0.00019
51	22	32	2.54951	0.91085	1	0.00289	0.00069	0.00087	0.00021
52	32	3	2.69258	0.91009	1	0.00305	0.00073	0.00023	0.00005
53	21	23	4.47214	0.94899	1	0.00506	0.00121	0.00141	0.00034

4.1.3 21 bus Electrical Distribution System Design

Figure 27 to Figure 29 below show the design for single feeder, two feeders, and three feeders distribution system based on Optimal Feeder Path Algorithm for 21 nodes system. Node numbered 1 in both figure represents the substation location.

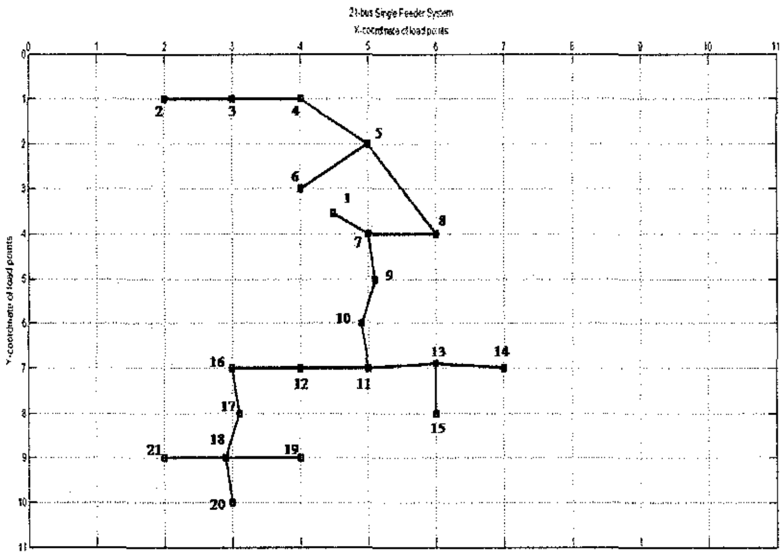

Figure 27 Single Feeder Distribution System Network (21 bus)

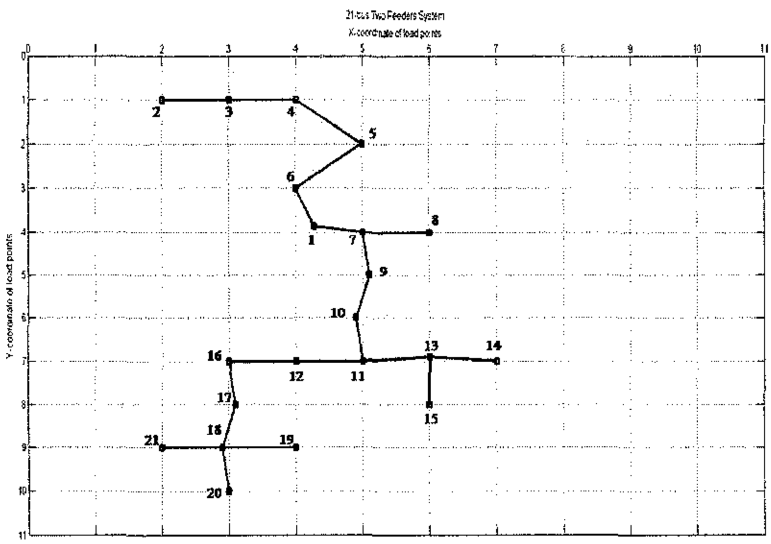

Figure 28 Two Feeders Distribution System Network (21 bus)

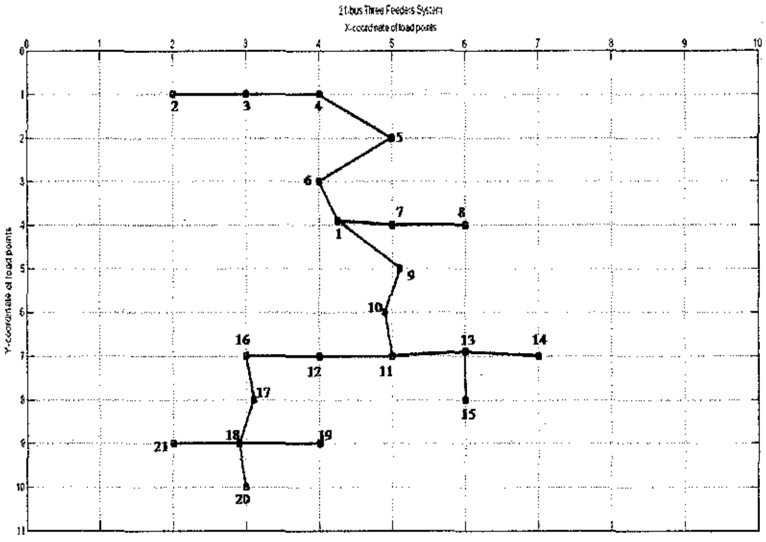

Figure 29 Three Feeders Distribution System Network (21 bus)

Table 7 shows the exact location of substation for single feeder, two feeders, and three feeders distribution system.

Table 7 Substation coordinates for three designs of 21 bus system

	x-coordinate	y-coordinate
Single feeder	4.4807	3.5471
Two feeders	4.2759	3.8451
Three feeders	4.2581	3.9004

4.1.4 21 bus Electrical Distribution System Analysis

Table 8 – Table 10 show the result from load flow analysis done to 54 bus single feeder, two feeders, and three feeders distribution system. The tables show the branch number, sending node, receiving node, distance in kilometer, voltage of receiving node, conductor type for branch j, resistance and reactance for branch j in p.u, and real and reactive power loss along branch j. For conductor type, 1 represents Squirrel, 2 for Weasel, 3 for Rabbit, and 4 for Raccon.

Table 8 Single feeder distribution system linedata (21 bus)

j	IS	IR	Dist(km)	V(IR)	cd	R(p.u)	X(p.u)	LP(pu)	LQ(pu)
1	1	7	0.68902	0.98809	4	0.00021	0.00016	0.50072	0.39422
2	7	8	1.00000	0.96413	2	0.00075	0.00026	0.08706	0.03011
3	7	9	1.00499	0.97440	4	0.00030	0.00024	0.45292	0.35658
4	9	10	1.01980	0.96121	4	0.00031	0.00024	0.41920	0.33003
5	10	11	1.00499	0.95014	4	0.00030	0.00024	0.30569	0.24067
6	11	12	1.00000	0.91906	3	0.00045	0.00025	0.15191	0.08309
7	12	16	1.00000	0.91047	3	0.00045	0.00025	0.13669	0.07476
8	11	13	1.00499	0.92584	3	0.00045	0.00025	0.00918	0.00502
9	16	17	1.00499	0.90405	3	0.00045	0.00025	0.07643	0.04180
10	13	14	1.00499	0.92473	3	0.00045	0.00025	0.00224	0.00123
11	17	18	1.01980	0.90158	3	0.00046	0.00025	0.01045	0.00572
12	18	21	0.90000	0.90103	3	0.00040	0.00022	0.00058	0.00032
13	18	20	1.00499	0.90097	3	0.00045	0.00025	0.00064	0.00035
14	13	15	1.10000	0.92516	3	0.00049	0.00027	0.00072	0.00039
15	18	19	1.10000	0.90091	3	0.00049	0.00027	0.00071	0.00039
16	8	5	2.23607	0.94659	2	0.00168	0.00058	0.16435	0.05683
17	5	4	1.41421	0.91162	1	0.00160	0.00038	0.04227	0.01009
18	4	3	1.00000	0.90767	1	0.00113	0.00027	0.01304	0.00311
19	3	2	1.00000	0.90502	1	0.00113	0.00027	0.00588	0.00140
20	5	6	1.41421	0.91536	1	0.00160	0.00038	0.01317	0.00314

Table 9 Two feeders distribution system linedata (21 bus)

j	IS	IR	Dist(km)	V(IR)	cd	R(p.u)	X(p.u)	LP(pu)	LQ(pu)
1	1	7	0.74046	0.98970	4	0.00022	0.00017	0.34988	0.27546
2	1	6	0.88901	0.99335	2	0.00067	0.00023	0.05933	0.02052
3	7	8	1.00000	0.96365	1	0.00113	0.00027	0.00127	0.00030
4	7	9	1.00499	0.97603	4	0.00030	0.00024	0.45141	0.35539
5	9	10	1.01980	0.96286	4	0.00031	0.00024	0.41776	0.32890
6	10	11	1.00499	0.95182	4	0.00030	0.00024	0.30462	0.23982
7	11	12	1.00000	0.92152	3	0.00045	0.00025	0.15111	0.08265
8	12	16	1.00000	0.91295	3	0.00045	0.00025	0.13595	0.07436
9	11	13	1.00499	0.92828	3	0.00045	0.00025	0.00913	0.00499
10	16	17	1.00499	0.90655	3	0.00045	0.00025	0.07601	0.04157
11	13	14	1.00499	0.92717	3	0.00045	0.00025	0.00223	0.00122
12	17	18	1.01980	0.90408	3	0.00046	0.00025	0.01039	0.00568
13	18	21	0.90000	0.90354	3	0.00040	0.00022	0.00057	0.00031
14	18	20	1.00499	0.90347	3	0.00045	0.00025	0.00064	0.00035
15	13	15	1.10000	0.92760	3	0.00049	0.00027	0.00072	0.00039
16	18	19	1.10000	0.90341	3	0.00049	0.00027	0.00070	0.00038
17	6	5	1.41421	0.98568	2	0.00106	0.00037	0.04969	0.01718
18	5	4	1.41421	0.97095	1	0.00160	0.00038	0.03726	0.00889
19	4	3	1.00000	0.96725	1	0.00113	0.00027	0.01148	0.00274
20	3	2	1.00000	0.96476	1	0.00113	0.00027	0.00517	0.00123

Table 10 Three feeders distribution system linedata (21 bus)

j	IS	IR	Dist(km)	V(IR)	cd	R(p.u)	X(p.u)	LP(pu)	LQ(pu)
1	1	7	0.74860	0.99868	1	0.00085	0.00020	0.00197	0.00047
2	1	6	0.93666	0.99299	2	0.00070	0.00024	0.06256	0.02163
3	1	9	1.38491	0.98127	4	0.00041	0.00033	0.61544	0.48453
4	7	8	1.00000	0.99749	1	0.00113	0.00027	0.00118	0.00028
5	9	10	1.01980	0.96817	4	0.00031	0.00024	0.41320	0.32531
6	10	11	1.00499	0.95718	4	0.00030	0.00024	0.30121	0.23714
7	11	12	1.00000	0.92937	3	0.00045	0.00025	0.14856	0.08126
8	12	16	1.00000	0.92088	3	0.00045	0.00025	0.13362	0.07308
9	11	13	1.00499	0.93607	3	0.00045	0.00025	0.00898	0.00491
10	16	17	1.00499	0.91453	3	0.00045	0.00025	0.07468	0.04085
11	13	14	1.00499	0.93498	3	0.00045	0.00025	0.00219	0.00120
12	17	18	1.01980	0.91209	3	0.00046	0.00025	0.01021	0.00558
13	18	21	0.90000	0.91155	3	0.00040	0.00022	0.00056	0.00031
14	18	20	1.00499	0.91148	3	0.00045	0.00025	0.00063	0.00034
15	13	15	1.10000	0.93540	3	0.00049	0.00027	0.00071	0.00039
16	18	19	1.10000	0.91143	3	0.00049	0.00027	0.00069	0.00038
17	6	5	1.41421	0.98532	2	0.00106	0.00037	0.04973	0.01720
18	5	4	1.41421	0.97041	1	0.00160	0.00038	0.03731	0.00890
19	4	3	1.00000	0.96670	1	0.00113	0.00027	0.01150	0.00274
20	3	2	1.00000	0.96421	1	0.00113	0.00027	0.00518	0.00124

4.2 Discussion

4.2.1 General Planning Process

In the methods used in this project, several assumptions are made in general. The assumptions are:

1) Base KVA for the simulation is taken as 100kVA.
2) Base Voltage is 11kV.
3) Base Reactance can be computed based on Base KVA and Base Voltage. The value for Base Reactance is 1210 ohm.
4) The convergence limit, DIFFx between iterations is 0.1. The convergence limit is the limit between PLOSS of current IT and previous IT.
5) The annual demand cost of losses, Kp is 2500 MYR/kW.
6) The energy cost of losses, KE is 0.5 MYR/kWh
7) T which is total hours in a year is 8760h.
8) Loss factor, Lsf used in the project is 0.2.
9) At first iteration, the voltages at all nodes are considered 1.0 p.u, and the real and reactive power losses at all the branches are 0.0 p.u.
10) The minimum voltage for all the buses is 0.9 p.u.

4.2.2 54 bus Distribution System

For the simulation of distribution design process on 54 bus system, two assumptions are made specifically for 54 bus system, (1) the initial guess for substation location for 54 bus system is [10.0, 10.0], (2) the power factor for all the buses in the system is 0.75.

Based on the results obtained in table 4, 5, and 6, they show that the bus voltage for all the buses are above the minimum voltage which is 0.9 p.u. The distribution planning method used satisfies the constraint of maintaining voltage above the minimum voltage.

Comparing the three designated system, three feeders system should be implemented as the distribution system because of its minimal real and reactive power losses, even though the total distance for three feeders is the higher compare with two feeders and single feeder system. Total distance only affects the installation cost of the system, however real power loss affects the operation cost of the system throughout its operation. Three feeders system also gives highest average bus voltage compared to other two designs. Hence, three feeders system should be implemented in designing distribution system for 54 bus system (Refer to Table 11).

Table 11 Comparison table of single, two, and three feeder distribution system (54 bus)

	Total Distance(km)	**Total Real Power Loss (p.u)**	**Total Reactive Power Loss (p.u)**	**Average Bus Voltage (p.u)**
Single Feeder	97.66161	1.30269	0.59056	0.92328
Two Feeders	97.91021	1.13459	0.45620	0.94135
Three Feeders	100.07107	0.88279	0.28130	0.95020

4.2.3 21 bus Distribution System

For the simulation of distribution design process on 21 bus system, two assumptions are made specifically for 21 bus system, (1) the initial guess for substation location for 21 bus system is [1.0, 1.0], and (2) the real and reactive load demand for all the buses in 21 bus system are specified (refer to APPENDIX E).

Based on the results obtained in Table 8 to Table 10, they show that the bus voltage for all the buses are above the minimum voltage which is 0.9 p.u. The distribution planning method used satisfies the constraint of maintaining voltage above the minimum voltage.

Comparing the three designated system, a comparison of results is given in Table 12. Three feeders system should be used as the distribution system because of its minimal real and reactive power losses, even though the total distance for three feeders is the higher compare with two feeders and single feeder system. Total distance only affects the installation cost of the system, however real power loss affects the operation cost of the system throughout its operation. Three feeders system also gives highest average bus voltage compared to other two designs. Hence, three feeders system should be implemented in designing distribution system for 21 bus system.

Table 12 Comparison table of single, two, and three feeder distribution system (21 bus)

	Total Distance(km)	**Total Real Power Loss (p.u)**	**Total Reactive Power Loss (p.u)**	**Average Bus Voltage (p.u)**
Single Feeder	21.92305	2.39384	1.63925	0.92690
Two Feeders	20.62743	2.07532	1.46236	0.94323
Three Feeders	21.06314	1.88009	1.30775	0.95001

CHAPTER 5
CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

Electrical Distribution Planning is an interesting project which would be beneficial to the utility and electrical consumers. Distribution planning is designed with initial guess of the substation location, and through iterative algorithms, the network configuration, and the conductor size for the branches can be obtained. MATLAB is used to simulate distribution planning on two systems, 54 bus system and 21 bus system. Three methods of planning is simulated and compared which are single feeder, two feeders, and three feeders configurations.

Based on the results obtained from the simulation, it is shown that utility should design a distribution system using three feeders configuration. Three configuration provides lower power losses and higher average bus voltage. Even though three feeders configuration need more distance, which increases the installation cost of the system, but with the operating cost of the system is much lower due to its lower power losses compared to single and two feeders configuration.

5.2 Recommendations

The method used to design electrical distribution system can be improved by integrating load growth into the load flow analysis algorithm. Integration of load growth is important in the aspect of expansion of the distribution system.

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APPENDICES

APPENDIX A

GANTT CHART

Activities / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Topic Selection	■							Mid Semester Break							
Preliminary Research		■	■	■											
Submission of Preliminary Report				■											
Mathematical Formula	■	■	■	■											
Modified load flow method simulation			■	■	■	■	■		■	■	■				
Multiple feeder design algorithm simulation			■	■	■	■	■		■	■	■				
54 bus system planning simulation			■	■	■	■	■		■	■	■				
21 bus system planning simulation									■	■	■				
Preparation for Interim Report										■	■	■	■	■	■
Submission of Interim Report										■	■	■	■	■	■
Oral Presentation										■	■	■	■	■	■

APPENDIX B

ACSR CONDUCTRO DATA SHEET

Type of Conductor	Cross Section, A(mm2)	Resistance (Ω/km)	Reactance (Ω/km)	Maximum Current Carrying Capacity (Amp)	Cost of Conductor(Rs/km)
Squirrel	20.9	1.37	0.327	131	1254.5
Weasel	31.6	0.908	0.314	169	1413.88
Rabbit	52.9	0.543	0.297	228	1777.45
Raccon	79.2	0.362	0.285	286	1939.04
	LSF = 0.20	Vmin = 0.95			

APPENDIX C

RECEIVING NODE VOLTAGE DERIVATION

From Figure 3.8, the following equation is obtained:

$$I(1) = \left(|V(1)|\angle\delta(1) - |V(2)|\angle\delta(2)\right) / R(1) + jX(1)$$

and

$$I(1) = \frac{P(2) - jQ(2)}{V(2)}$$

From equation a and b, the following is obtained:

$$\frac{|V(1)|\angle\delta(1) - |V(2)|\angle\delta(2)}{R(1) + jX(1)} = \frac{P(2) - jQ(2)}{V(2)}$$

Therefore

$$|V(1)||V(2)|\angle\delta(1) - \angle\delta(2) - |V(2)|^2 = [P(2) - jQ(2)][R(1) + jX(1)]$$

Therefore

$$|V(1)||V(2)|\cos[\delta(1) - \delta(2)] - |V(2)|^2 + j|V(1)||V(2)|\sin[\delta(1) - \delta(2)]$$
$$= [P(2)R(1) + Q(2)X(1) + j[P(2)X(1) - Q(2)R(1)]$$

Separating real and imaginary part of equation c

$$|V(1)||V(2)|\cos[\delta(1) - \delta(2)] - |V(2)|^2 = P(2)R(1) + Q(2)X(1)$$

Therefore

$$|V(1)||V(2)|\cos[\delta(1) - \delta(2)] = |V(2)|^2 + P(2)R(1) + Q(2)X(1)$$

Squaring and adding equation a and b

$$|V(1)|^2|V(1)|^2 = [|V(2)|^2 + P(2)R(1) + Q(2)X(1)]^2 + [P(2)X(1) - Q(2)R(1)]^2$$

Or

$$|V(2)|^4 + 2.0[P(2)R(1) + Q(2)X(1) - 0.50|V(1)|^2]|V(2)|^2 + (R(1)^2 +$$
$$X(1)^2)(P(2)^2 + Q(2)^2)) = 0$$

Equation v can further be simplified because in distribution system, the voltage angle is not so important. Rewritting equation v, one obtains:

$|V(2)| = \{[(P(2)R(1) + Q(2)X(1) - 0.5|V(1)|^2])^2 - (R(1)^2 + X(1)^2)(P(2)^2 + Q(2)^2))]^{0.5} - (P(2)R(1) + Q(2)X(1) - 0.5|V(1)|^2)\}^{2}$

Equation x can be written in generalized form:

. Equation (3) can be generalized in the form of:

$$|V(m2)| = [B(j) - A(j)]^{0.5} \tag{4}$$

$$A(j) = P(m2) * R(j) + Q(m2) * X(j) - 0.5 * |V(m1)|^2 \quad ()$$

$$B(j) = \{A(j)^2 - [R(i)^2 + X(j)^2] * [P(m2)^2 + Q(m2)^2]\}^{0.5} \tag{5}$$

APPENDIX D

54 BUS DATA

i	x-coordinate	y-coordinate	SL
1	10.0	10.0	0
2	1.0	2.0	25000
3	2.0	15.0	25000
4	3.0	4.0	25000
5	4.0	12.0	50000
6	5.0	11.5	63000
7	6.0	10.0	63000
8	7.0	7.0	50000
9	1.5	5.5	25000
10	11.5	13.5	16000
11	7.5	17.5	16000
12	8.5	15.5	25000
13	12.5	10.5	50000
14	11.0	17.5	63000
15	8.0	7.5	63000
16	11.0	6.0	25000
17	5.5	5.5	16000
18	3.5	8.5	16000
19	13.0	8.0	16000
20	14.0	13.0	63000
21	16.5	14.0	25000
22	5.5	17.0	25000
23	20.5	12.0	50000
24	8.0	9.0	100000
25	5.0	7.0	100000
26	8.0	5.5	100000
27	10.5	8.0	50000
28	10.5	15.0	50000
29	9.0	19.0	25000
30	7.5	19.5	63000
31	5.5	19.5	63000
32	3.0	17.5	25000
33	13.0	15.5	50000
34	14.0	16.5	50000
35	12.5	19.0	25000
36	11.0	20.0	25000
37	5.0	15.5	50000
38	2.0	10.5	50000
39	3.0	3.5	63000
40	6.0	4.0	25000

41	9.0	4.5	25000
42	14.0	11.5	50000
43	15.0	10.0	50000
44	15.0	14.5	25000
45	15.5	12.5	25000
46	12.0	12.0	63000
47	14.5	7.5	63000
48	13.5	6.0	25000
49	13.0	4.5	16000
50	13.5	18.0	16000
51	4.0	5.0	25000
52	9.5	6.5	16000
53	9.5	17.0	25000
54	12.0	2.5	50000

APPENDIX E

21 BUS DATA

i	x-coordinate	y-coordinate	PL	QL
1	1.0	1.0	0	0
2	2.0	1.0	200000	50000
3	3.0	1.0	100000	20000
4	4.0	1.0	150000	60000
5	5.0	2.0	200000	50000
6	4.0	3.0	250000	80000
7	5.0	4.0	50000	5000
8	6.0	4.0	100000	20000
9	5.1	5.0	200000	100000
10	4.9	6.0	500000	200000
11	5.0	7.0	900000	200000
12	4.0	7.0	100000	20000
13	6.0	6.9	100000	20000
14	7.0	7.0	200000	50000
15	6.0	8.0	100000	50000
16	3.0	7.0	400000	100000
17	3.1	8.0	750000	90000
18	2.9	9.0	100000	40000
19	4.0	9.0	100000	40000
20	3.0	10.0	100000	40000
21	2.0	9.0	100000	40000

APPENDIX F

DISTRIBUTION SYSTEM PLANNING SOURCE CODE

```
%=========================================================================
%ALGORITHM-1 OPTIMAL FEEDER PATH ALGORITHM(SINGLE FEEDER)
%=========================================================================
function linedata = singlefeeder()
%declaration of variables used in OPTIMAL FEEDER PATH ALGORITHM
NB=54;%total number of nodes in the system
LN1=NB-1;%total number of branches in the system
busdata = busdata54();
connodes=busdata(1,1:4);
unconnodes=busdata(2:NB,1:4);
CN=1;
UCN=NB-CN;
linedata=[];%declare linedata variables to store linedata of system
designed
distance=0;%stores minimum distance in every iteration to be updated in
linedata
doublesender=55;%initial value for doublesender
feeder=1;
j=1;
while j<=feeder
    mindistance=100;
    uc=1;
    while uc <= UCN
    distance(uc,j)=sqrt((busdata(1,2)-unconnodes(uc,2))^2+(busdata(1,3)-
unconnodes(uc,3))^2);
    if mindistance > distance(uc,j)
        mindistance=distance(uc,j);
        ucx=uc;
    end
    uc=uc+1;
    end
    linedata(j,1)=j;
    linedata(j,2)=busdata(1,1);
    linedata(j,3)=unconnodes(ucx,1);
    linedata(j,4)=mindistance; %distance of branch j
    connodes(j+1,:)=unconnodes(ucx,:);
    unconnodes(ucx,:)=[];
    CN=CN+1;
    UCN=UCN-1;

    j=j+1;
end
dsn=1;
while j <= LN1
    mindistance = 100;
    c=1;
    while c <= CN
        if j >3
            d1=1;
            while d1 < j
                d2=d1+1;
                while d2 < j
                    if linedata(d1,2)==linedata(d2,2)
                        doublesender(dsn)=linedata(d1,2);
                        dsn=dsn+1;
                    end
```

```
                d2=d2+1;
            end
            d1=d1+1;
        end
    end

    ds=1;
    uc=1;

    while uc <= UCN
        if j > 1 && connodes(c,1)==linedata(1,2)
            break
        end

        if connodes(c,1)==doublesender(ds)
            break
        else
            distance = sqrt((connodes(c,2)-
unconnodes(uc,2))^2+(connodes(c,3)-unconnodes(uc,3))^2);
            if mindistance > distance
                mindistance = distance;
                cx=c;
                ucx=uc;
            end
        end

        uc=uc+1;
    end
    c=c+1;
end

linedata(j,1)=j; %branch number
linedata(j,2)=connodes(cx,1); %sending end node of branch j
linedata(j,3)=unconnodes(ucx,1); %receiving end node of branch j
linedata(j,4)=mindistance; %distance of branch j
connodes(j+1,:)=unconnodes(ucx,:);
unconnodes(ucx,:)=[];
CN=CN+1;
UCN=UCN-1;

j=j+1;
end
end
```